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ADAPTIVE AIDING FOR SYMBIOTIC HUMAN-COMPUTER CONTROL: CONCEPTUAL MODEL AND EXPERIMENTAL APPROACH

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FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
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This report summarizes development of an experimental approach to investigation of benefits of adaptive aiding. A conceptual framework of the human-computer interface is presented. and its implications for the design of adaptive aids is discussed. The conceptual framework contains parallel elements for both the operator and the computer and emphasizes those factors expected to be important to successful cooperative task performance. A laboratory task for empirical investigation of some of the important design issues is presented. The task environment includes two competing tasks which must be performed simultaneously: a target spotting task and a tracking task. The target spotting task may be adaptively aided or not, depending on experimental conditions. This type of task was chosen for the investigation of adaptive aiding because it relies greatly on pattern recognition, an activity to which human operators and computers can both make important contributions. The tracking task is included to provide a means of varying competing workload, a factor which is expected to alter the usefulness of the aid for the spotting task. Results of pilot testing with this task are presented.

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SUMMARY

This report outlines the development of a conceptual framework and experimental task environment for investigation and specification of design principles for adaptive aids. Adaptive aids are those that partition, allocate, or transform the task at hand dynamically, in response to overall system performance. Adaptive aids are of interest because this type of aiding appears to offer the potential of incorporating operator strengths, while guarding against deficiencies. However, successful application of this concept will, over the long term, depend upon the resolution of some fundamental questions in the area of human-computer interaction.

The first part of this report reviews the issues considered relevant to human-computer interaction in a decision-aided environment, and postulates a general framework for research in this area. The framework contains parallel sub-models for both the human operator and the computer, and emphasizes the human-computer partnership inherent in an aided environment. This framework is useful for systematic consideration of issues that will affect operator employment of an aid and the overall impact of an aid on task performance.

The task environment developed for laboratory investigation of adaptive aiding is described in detail. It includes two competing tasks which must be performed in parallel. One task, which may be aided or not, dependent upon experimental conditions, involves identifying ("spotting") targets of a particular type. This task is heavily dependent upon pattern recognition, a task for which humans and computers have important and complementary abilities. The second task is a tracking task, used here to introduce competing workload of varying difficulty.

Finally, the results of some preliminary research with this task environment are presented. In this study, only the tracking and spotting task difficulty were manipulated; no aiding was available. These results indicate that the manipulation of spotting task difficulty did affect performance, and that the magnitude and pattern of the performance changes were large enough and systematic enough for adaptive aiding to be useful in this environment.

PREFACE

This work was performed for the Human Engineering Division, Air Force Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base, in support of Project 2312-V2-33, Design Principles for Adaptive Decision Aids. The work was conducted by Search Technology, Inc. under subcontract to Alphatech, Inc., Contract Number F33615-82-C-0509.

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INTRODUCTION

With the increasing complexity of systems, it has become necessary to consider providing the human operator with some assistance in performing tasks required for system operation. The idea of aiding the operator is not new, and assistance has traditionally been in the form of some mechanized or computer-based aid capable of performing some of the operator's tasks. Thus, a "classic" issue in the study of man-machine systems has been the appropriate allocation of tasks to human or computer.

The decision as to which tasks would be performed by computer has all too often been based upon which tasks could be automated. In situations where total automation was not feasible, the task allocation decision has been based upon relative abilities of humans and computers. For example, humans would be given tasks requiring flexibility, and tasks requiring consistency would be given to computers. A number of lists of human vs. computer abilities are available to guide task allocation decisions (e.g., Licklider, 1960).

For a number of reasons, this approach to computer aiding appears less than satisfactory. For example, due to progress in artificial intelligence, the distinction between human and computer abilities is much less clear, and it is possible to view

the human and computer as partners with abilities which may partially overlap. As a result, allocation of tasks based solely upon computer abilities may be inappropriate.

Another factor which should be considered is individual differences. Human aptitudes and abilities, cognitive styles, and attitudes have been cited as affecting human behavior in a number of situations. Lists of characteristics of a prototypical human do not reflect these differences.

Human performance may be expected to vary not only across individuals, but also within individuals over time. Performance may improve with practice, and may degrade as the human becomes fatigued. Because of the dynamic nature of many systems, task demands may change over time. The quality of human performance may reflect changes in task difficulty and in the nature of tasks which must be performed concurrently.

Finally, the quality of the computer's performance may depend upon conditions. For example, if the ..ality of information essential to the computer's perfomance is degraded, performance will suffer. The computer's performance may also be unsatisfactory if the models which serve as the basis for the computer's performance are not appropriate for the current situation.

In light of these shortcomings, it seems desirable to make computer aids adaptive. An adaptive aid could step in when needed and provide assistance in a form appropriate to the situation. In situations where no assistance was needed, the aid could remain inactive. It has been demonstrated in principle that such an approach to aiding could improve overall system performance substantially (Rouse, 1981).

Relevant Issues

The concept of adaptive aiding is not totally new (e.g., Chu & Rouse, 1979; Rouse, 1975, 1981). However, it has not been implemented in any real-world applications, probably because the manner in which this should be done is not at all straightforward. There are many issues which should be considered in order to progress. For example, what should the focus of adaptation be? Should the aid be adapted to group characteristics, or to individuals? Should adaptation be done once, or dynamically over time?

Another issue is the method of adaptation. At least three approaches are imaginable. As discussed previously, tasks may be allocated, with either human or computer in control of performance. Alternatively, a task may be partitioned between the two partners, with each performing task components. Finally, one partner may assist the other by performing a transformation of a task (e.g., the computer may filter noise from a visual

display, or may alter the mode of information presentation dependent upon conditions).

If human and computer are to be partners, then there must be some means for the two to communicate. But what should be the <u>nature of communication</u>? If communication is explicit, there is less uncertainty as to what is being communicated, but the human must invest resources in receiving and transmitting information. This resource demand may be less if communication is implicit, but there may be less certainty as to what is communicated. There may also be a need for the human to invest resources into determining what the computer is doing.

When system control is shared by human and computer, <u>which partner should be in charge</u>? Suppose tasks are to be allocated dynamically. Which partner should make the decision as to task allocation? It seems that the answer to this question is dependent upon conditions, and as with the nature of communication, the resources required to make decisions and inform the partner must be considered.

Finally, if it appears that it would be advantageous to have the computer make decisions such as task allocation, <u>what is the basis for decision making</u>? If such decisions are to be possible, it will be necessary to imbed models in the computer's knowledge base to support them. These models must incorporate

characteristics of the task situation, the human's task performance, and the computer's task performance in order to be effective. Development of these models will require the incorporation of results of research in human problem solving and information processing, along with insights gained through specific research in human-computer interaction.

Scope of this Report

The issues described as being relevant to human-computer interaction are discussed in greater detail in a report completed during the first year of this effort (Rouse & Rouse, 1983). In that report, a general framework was presented for research in human-computer interaction in the context of decision aiding. The goal of this year's effort was to develop an experimental environment which could serve as a tool for investigating some of these issues, and to begin conducting experiments. The task environment which was developed is presented in the third section of this report, and the results of pilot research using the environment are presented in the fourth section.

When discussing what characteristics the experimental environment should have, it became clear that answers to the questions posed in the first-year report depended upon the interactions of a number of variables. To insure that these variables could be manipulated as necessary within the environment created, it was felt that effort should be devoted to

a more detailed consideration of the relationships between them. The result of this effort was a conceptual model of human-computer interaction, which is also presented in this report. Since the development of the model had a considerable impact upon the nature of the experimental scenario, it is presented in the following section.

CONCEPTUAL MODEL OF HUMAN-COMPUTER INTERACTION

Before proceeding with a detailed presentation of the model, it is necessary to define the type of situation in which it applies. The analysis presented here was developed with the idea of providing dynamic adaptation dependent upon current task conditions, rather than static adaptation to a particular type of situation or individual. Furthermore, only one method of adaptation was considered: task allocation. The decision was made to focus on task allocation in order to maintain a manageable number of relevant relationships which must be considered. Undoubtedly, many of the relationships expressed are also applicable to other methods of adaptation (i.e., partitioning and transformation); the extent of this applicability will be assessed at a later date.

A Scenario

As an illustration of the type of situation represented by the model, consider the following scenario. Imagine the human

operator of a system is responsible for performing multiple tasks. For example, an aircraft pilot may navigate, communicate with air traffic control and other aircraft, monitor numerous instruments, and manually fly the plane. Should a malfunction occur, the pilot may also attempt to compensate for the failure and identify its source.

Since humans do not have infinite capacity to process information, it is conceivable that the human operator may be unable to perform all of these tasks satisfactorily. This is particularly true if a number of them must be performed simultaneously. It may be expected that the human's task performance would degrade as a function of the number and difficulty of the tasks which must be performed.

Imagine now that a computer aid is available, which is capable of performing a subset of the human's tasks. Thus, the human's repertoire of tasks consists of tasks which may be performed by human or computer (shared tasks), or by human alone (nonshared tasks). The aid's performance of the shared tasks is not as good as the human's best performance of these tasks, but the aid may be better than the human if the human's performance degrades. Furthermore, the quality of the aid's performance may be affected by the nature of the current situation.

Since neither the human nor computer is clearly superior in performance under all conditions, dynamic allocation of the shared tasks is desirable. For example, the aid could assist the human by performing some of the tasks when the human's performance of shared or nonshared tasks degrades to an unacceptable level. At other times, the human could perform all of the tasks without help. Of course, the aid could also assist the human in deciding which partner should perform which tasks, and which partner should decide who should make the task allocation decisions. The following model is an attempt to represent such a situation.

To facilitate understanding, the model is presented in phases. First, variables affecting human performance of dynamic tasks are considered. Then, computer performance is considered in a similar manner. Finally, the submodels of the hu and computer are combined to form the complete model, and relationships important to the interaction of the two partners are discussed.

Model of the Human

Overview

The model of the human's task performance is shown in Figure 1. Characteristics of the task situation are shown across the bottom of the figure (labeled T1, T2, and T4). The human is represented in the top portion of the figure (with components

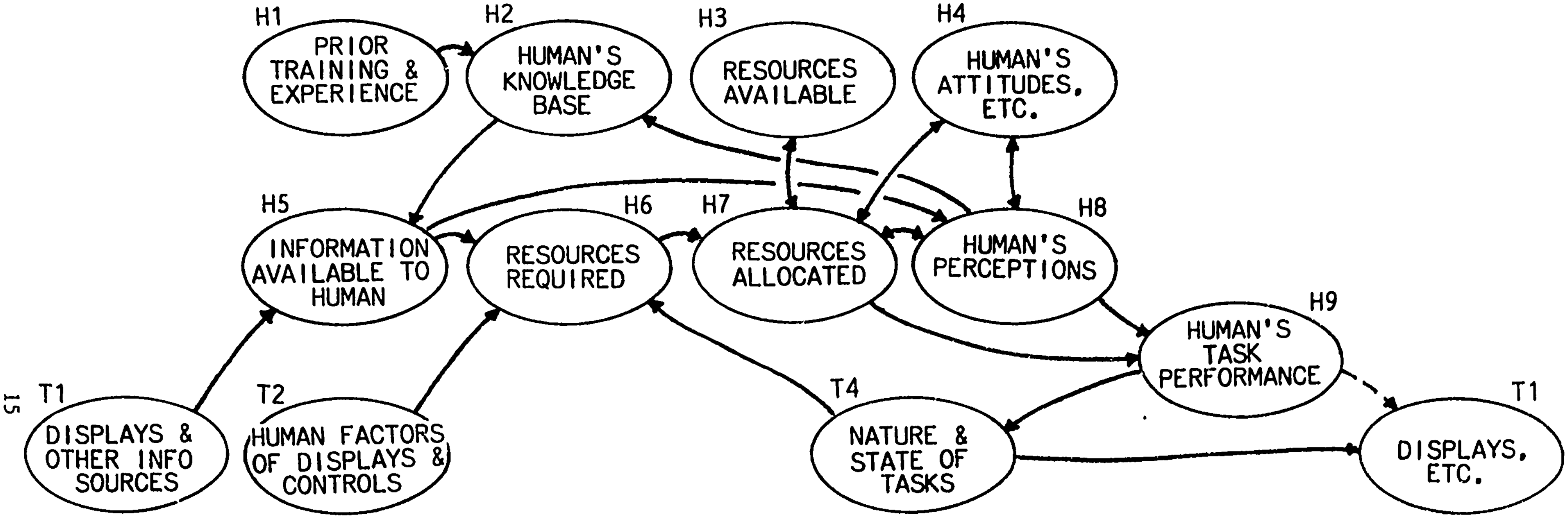

Figure 1. Model of human performance.

designated H1 through H9). Figure 1 may be viewed as an "influence diagram", with arrows interpreted to mean "has an effect upon". Solid arrows represent probable effects, and broken arrows represent effects which are possible but dependent upon conditions. Thus, the human's knowledge base (component H2) is viewed as having a probable effect upon the availability of information (H5), but the human's task performance (H9) may directly affect displays (T1) only if such information is chosen to be displayed.

The human's task performance is represented near the right of the figure. With the exception of prior training and experience (H1), other components represent intervening variables. Four general areas are discussed in greater detail: perceptions (H8), information (H5), resources (H3, H6, and H7), and attitudes (H4). Perceptions, information, and resources are discussed under separate headings; the effects of attitudes are presented in conjunction with these other factors.

Components of the Model

Perceptions. As may be noted from Figure 1, how the human perceives the task situation is quite important. "Human's perceptions" is one of the few components of the model with a direct impact upon performance. Logically, it may be expected that task performance would be affected by characteristics of the situation such as the nature of displays and controls and the

nature of the tasks themselves. However, the relationships between these factors and the human's behavior are not viewed as being direct. The human's performance must be based upon how the situation is perceived rather than objective reality. A number of perceptions are relevant, including the human's perception of the nature and state of the tasks, the quality of his or her own performance, and the criteria for acceptable performance. As indicated in the model, perceptions may be influenced by several other factors.

Information. One of these factors is task-relevant information. Information available to the human (H5) may be affected by the human's knowledge base (H2) (and hence, prior training and experience, H1) and the nature and content of other information sources (T1). There are two characteristics of this information which are important here: quality and accessibility. The quality of information refers to its accuracy and sufficiency. Accessibility refers to the actions required to retrieve the information.

Each of these characteristics may be affected by the human's knowledge base and other information sources. Quality is affected if the human's knowledge or available information is inaccurate or incomplete. Information is more or less accessible, dependent upon where it may be found (e.g., in the human's memory, online and currently displayed, online but not

currently displayed, offline in hardcopy form, or in a colleague's memory).

The quality of information available to the human may have a direct effect upon the human's perceptions of the situation. Accessibility may also affect perceptions, but the influence is less direct, via an influence upon the resources required to retrieve information. In this formulation, it is assumed that retrieval of information which is not available would require infinite resources.

Resources. "Resources" in this model is intended to mean the same thing as it does in attention and workload research. It is assumed that the human's attentional resources consist of multiple resource pools, although this assumption is not necessary for the model. In fact, resources need not be limited to mental information processing resources; most of the relationships expressed here are compatible with the inclusion of physical effort as well. There are three components of the model which refer to resources: resources required (H6), resources available (H3), and resources allocated (H7). These may be affected by different factors and may in turn have different effects upon the human's performance.

As noted earlier, resources required to obtain information may be affected by the accessibility of that information. If the

information is available online but must be requested by the human, then the human factors of displays and controls (T2) may also affect the resources required to retrieve it. Failure to allocate sufficient resources to retrieving information could affect the accuracy of the human's perceptions. Resources required for task performance may be affected by the human factors of displays and controls used to perform the tasks, and the nature and states of the tasks. As indicated, resources allocated to task performance may have a direct effect upon that performance.

"Resources available" represents the human's "spare capacity" at any given time, and imposes a limit to the amount of resources which may be allocated to performing tasks or retrieving information. As indicated by the double-headed arrow, resources available and resources allocated have reciprocal effects upon each other. As more resources are available, more resources may be allocated; however, as more resources are allocated to a task, there are fewer resources available to allocate to other tasks.

Resources allocated may be affected by factors other than resources available and resources required. For example, the human's perceptions of the task situation and demand characteristics may influence resources allocated to task performance. It is possible that the human may try to minimize

resource allocation, independent of resource availability, due to a lack of motivation.

Perceptions and attitudes may interact in their effects upon resource allocation. These relationships are illustrated in Figure 2. (The components introduced in Figure 2 are defined in Table 1.) In order to explain these relationships, it is necessary to elaborate upon the concepts of "perceptions" and "attitudes". Two perceptions are included here: the human's perception of the task situation, and the human's perception of the accuracy and completeness of his or her situation assessment (i.e., feelings of uncertainty). It is the human's feelings of uncertainty, rather than the accuracy of his situation assessment, which motivate information retrieval. Thus, it is possible for the human to have misperceptions about the task situation and still fail to allocate resources to retrieving information due to misplaced confidence in the accuracy of perceptions.

The effects of uncertainty on information retrieval may be mediated by the human's attitude toward uncertainty (i.e., the degree to which feelings of uncertainty may be tolerated). Slight feelings of uncertainty could cause the human to allocate resources to obtain information if there is a low tolerance for uncertainty. On the other hand, the human might fail to retrieve information in spite of a high degree of uncertainty, given that the tolerance for uncertainty is also high.

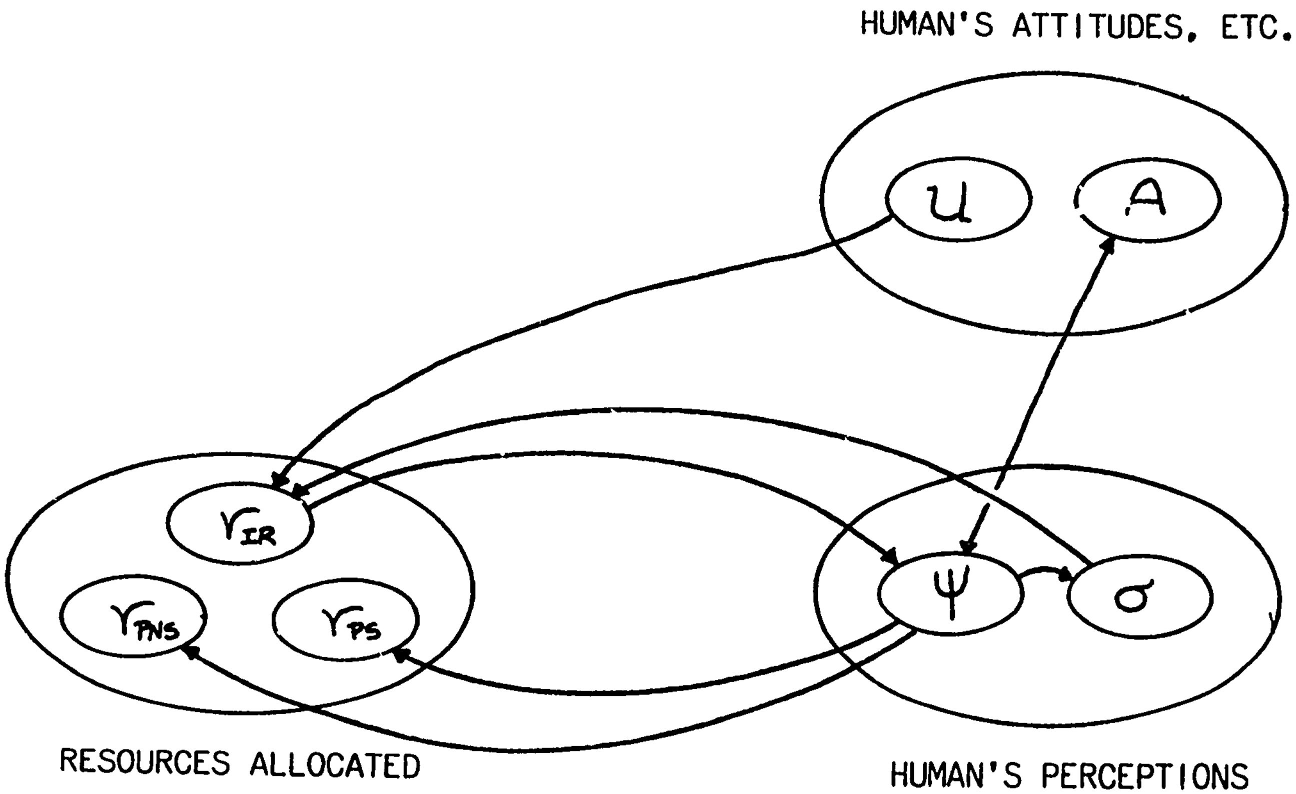

Figure 2. Relationships between resources allocated, attitudes, and perceptions.

Table 1

Definitions of Model Components Introduced

in Figures 2 and 5

rIR	resources allocated to retrieving information
rPNS	resources allocated to performing the nonshared task (i.e., tracking)
rPS	resources allocated to performing the shared task (i.e., identifying targets)
Ψ	human's perceptions of the task situation, own performance, computer's performance (if applicable), and performance criteria
σ	human's uncertainty as to the accuracy of perceptions
U	human's tolerance for uncertainty
A	human's acceptance
rIT	resources allocated to transmitting information
nC	human's need to be in control

Model of the Computer

Imagine now that tasks are performed by the computer rather than the human. A model of the computer's task performance is presented in Figure 3. As may be discerned immediately, the model shown in Figure 3 is less complex than the model of the human in Figure 1. This is due to the focus on the human in this research effort. The concern here is not how the computer performs its tasks, but merely that it does perform them. The components which are included in this model are parallel to components in the human's model, with the following distinctions.

As with the human, information available to the computer (C5) may be affected by the computer's knowledge base (C2) and other information sources. The computer's knowledge base may consist of stored facts and models for assessing the task situation and performing tasks. The information sources available to the computer may overlap with those available to the human (T1), but they may not be identical. For example, the human may be able to ask questions of a colleague, and the computer may be able to sense system state variables which are inaccessible to the human.

It is the quality of information which is of primary importance to the computer. Accessibility is less important than with the human, because it is assumed that the computer has no

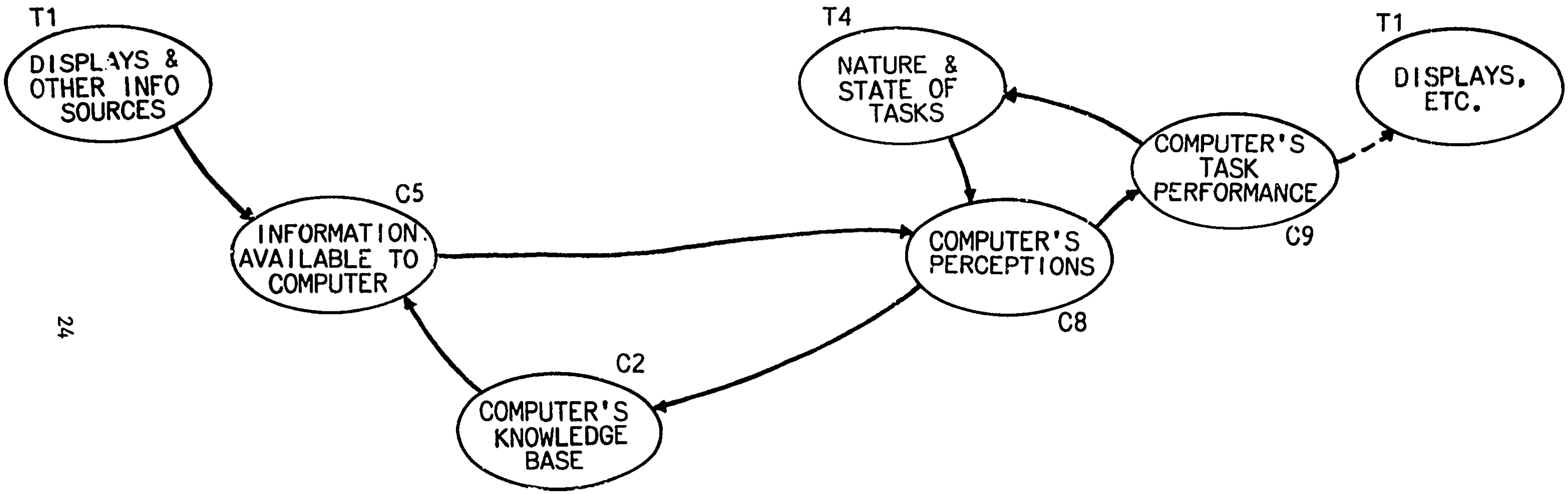

Figure 3. Model of computer performance.

resource constraints and does not choose whether or not resources should be allocated to certain tasks. As with the human, th. quality of available information has an effect upon the computer's "perceptions" of the situation (C8). "Computer's perceptions" represents the computer's assessment of the task situation, and is so labeled to reflect the parallel to human perceptions.

Model of Human-Computer Interaction

Overview

The complete model is shown in Figure 4. This figure is a composite of Figures 1 and 3, and represents the situation described earlier, in which a subset of the human's tasks may be performed by the computer. The top part of Figure 4 is the model of the human, and the model of the computer is shown at the bottom of the figure.

When human and computer are partners, three additional components are necessary: the nature of human-computer communication (T3), the human's decisions (H10), and the computer's decisions (C10). "Nature of communication" refers to one of the issues discussed in the introduction of report. The two "decisions" components refer only to decision which must be made as a result of having a partner (e.g., which par should perform a task); decisions required for task performance

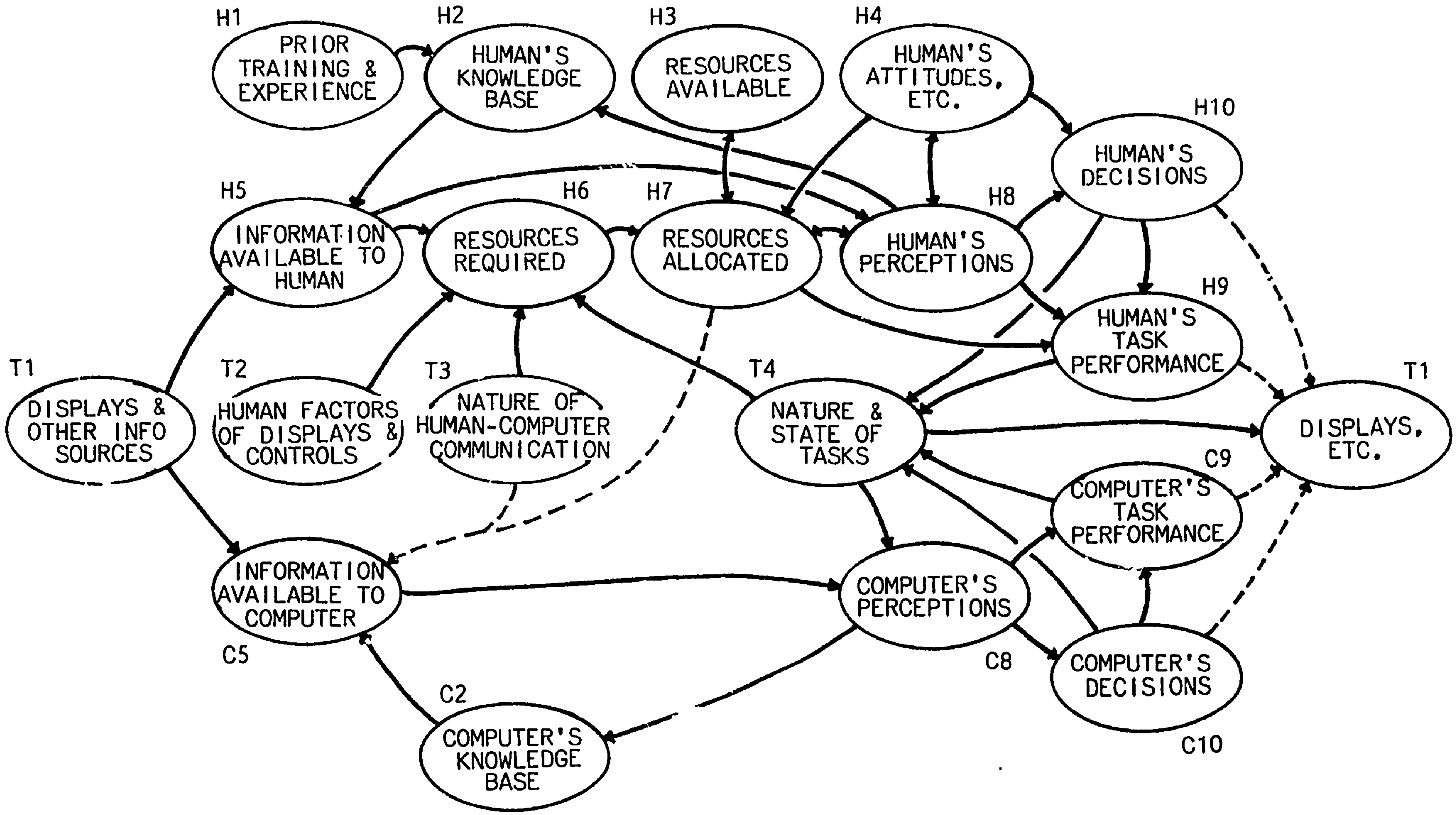

Figure 4. Model of human-computer interaction.

are included in components C9 and H9. Strictly speaking, "nature of communication" could have been included in the nature and state of the tasks, and the two "decisions" could have been incorporated in their respective "performance" components. However, since this is intended as a model of human-computer interaction, they have been separated because of their importance.

The presence of a partner imposes additional information requirements for both human and computer. Not only must one gather information relative to one's own task performance, but it is also necessary to be aware of what one's partner is doing. Besides the necessity of knowing which partner is currently in charge of performing a given task, other information may be required. For example, both partners should agree as to which of them is in charge of making task allocation decisions. The partner making these decisions should have an idea of the relative ability of each partner to perform tasks and the conditions in which performance may be expected to excel or degrade. Ideally, the decision maker should also be able to make an accurate assessment of current conditions.

Human Issues

Additional relationships relevant to human performance emerge as a result of having a computer aid. Because of the information requirements accompanying the introduction of a

partner, there may be a change in the resources required to retrieve information. Furthermore, if the human must transmit some information to the computer (e.g., a decision as to which partner should perform a given task), then resources will be required to make that transmission. As indicated in Figure 4, these resource requirements are affected by the nature of human-computer communication (e.g., whether communication is implicit or explicit).

Accompanying this change in resources required, there may be a change in resources allocated. As noted in the earlier discussion of the human, resources allocated may also be affected by human perceptions and attitudes. Figure 5 attests to the complexity of these relationships, where the additional components rIT, nC, and A (see Table 1 for definitions) are introduced.

As may be observed in Figure 5, a great deal depends upon the human's acceptance of the computer. There are two types of acceptance which are important: the human's acceptance of the computer's task performance, and the human's acceptance of the computer's allocation decisions. Failure to accept the computer's task performance could affect the amount of resources allocated to retrieving and transmitting information; the human might monitor the computer's performance more than necessary, and could be less likely to transmit information required by the

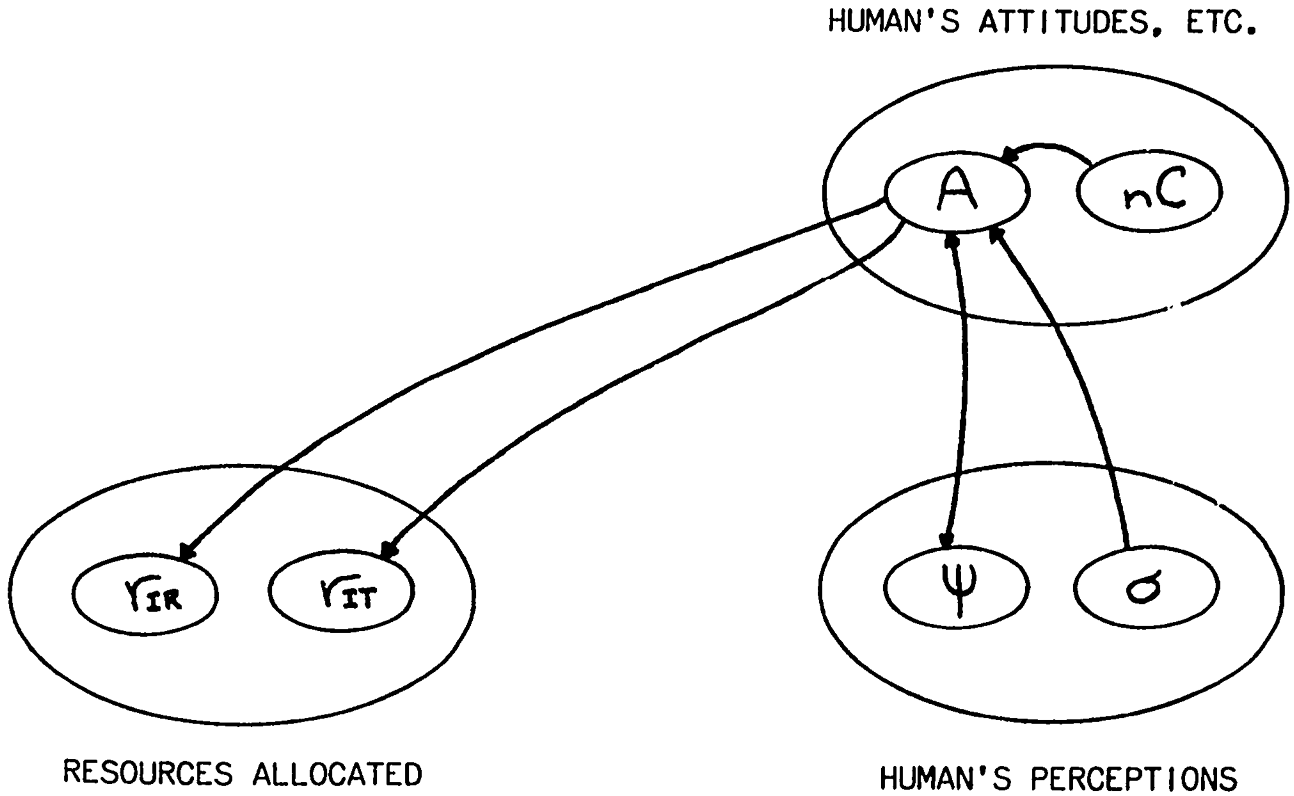

Figure 5. Additional relationships between resources allocated, attitudes, and perceptions, due to human-computer interaction.

computer. (Note the possible effect of resources allocated upon information available to the computer.) Failure to accept the computer's decisions could lead to attempts to override the computer, which in the context of Figure 4, can be viewed as a human decision to preempt the computer's decision.

The human's acceptance of the computer is probably inversely related to a need to be in control of the situation. Acceptance may also be influenced by the human's perceptions of his or her own and the computer's performance, and by the degree to which the human is confident about the accuracy of these perceptions. (Note also that perception may be affected by acceptance.) It is hypothesized that uncertainty and perceived performance may combine in their effects upon acceptance, as shown in Figure 6.

The graph on the left in Figure 6 may be interpreted as follows. If the human perceives that his or her own performance is poor, acceptance of the computer is more likely than if perceived performance is good. This effect is greater if uncertainty about one's performance is high. In the graph on the right, it may be seen that the opposite effects are anticipated with respect to the human's perceptions of the computer's performance. The human's acceptance of the computer should be greater if the perception of the computer's performance is good and if there is little uncertainty about it.

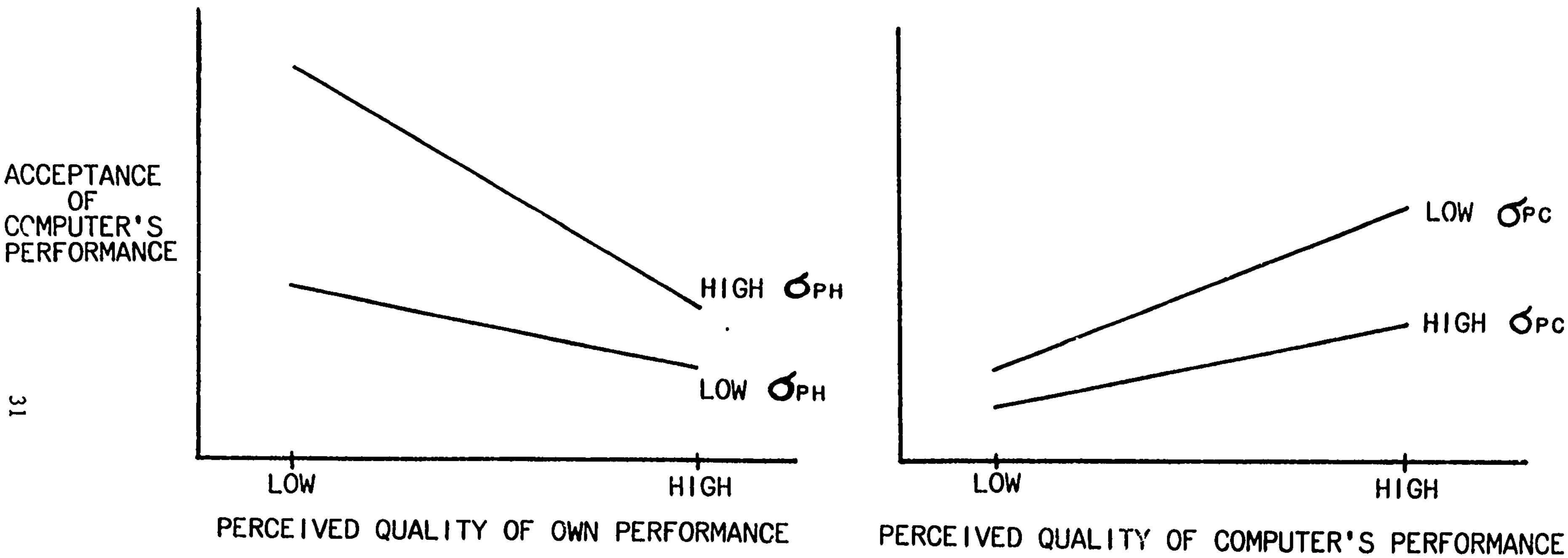

Figure 6. Relationships between perceptions, uncertainty, and acceptance.

Finally, note in the complete model (Figure 4) that the human's attitudes and perceptions may affect decisions as to the allocation of decision making and task performance. The human's decisions may be made based upon perceptions of the computer's performance relative to one's own. If these perceptions are inaccurate, then the quality of decisions may be expected to suffer. Even if the human's perceptions are accurate, the human may not make appropriate decisions because of attitudes toward the computer (including acceptance of the computer and need to be in control).

Computer Issues

The model of the computer remains essentially the same as before, with the exception of the new "decisions" component. As noted earlier, the introduction of the human partner carries with it more information requirements; hence the computer's knowledge base may be expected to contain more models, including models of the human. It is important to note the relationship between information available to the computer and resources allocated by the human. If the computer depends upon the human for information, there is a possibility that the human will supply the computer with incomplete or inaccurate information. This in turn could affect the quality of the computer's decisions and task performance.

Implications of the Model

If the relationships expressed in the model are accepted, there are a number of implications for design and research in computer aiding. First, it may be noted that there are quite a few intervening variables between the traditional inputs (e.g., training and human factors) and the human's performance. If prediction of the human's performance and/or providing the computer with a model sufficient to support adaptive aiding is to be possible, these intervening variables must be considered. It is difficult to imagine that the results desired may be achieved by focusing exclusively on issues such as the impact of training or alternative display designs. It seems reasonable to expect that an assessment of these issues should be tempered by an understanding of the relationships between the variables identified in the model.

In light of the direct effects upon performance, the quality of the human's perceptions of the situation, his or her own performance, and the computer's performance is very important. Hence, the human must be provided with quality information, with form and content designed so as to lead to appropriate perceptions. Resource constraints indicate that this information must also be readily accessible to the human, or it may not be retrieved when needed. In other words, the resources required to perform the tasks and retrieve/transmit information must "match" the resources available to do so.

The nature of human-computer communication is of major importance as the information link between human and computer. As noted in previous reports, one relevant characteristic of human-computer communication is the degree to which information transfer is explicit. At one extreme, communication between the partners may be entirely implicit, with each partner inferring what the other is doing. At the other extreme, all information may be explicitly shared, with nothing left to chance. Intuitively it seems that neither of these approaches is desirable; one seems too "cumbersome", and the other too "risky". But what would constitute an appropriate level of explicitness? As the model suggests, the answer to this question depends upon a number of factors, including the combination of tasks the human must perform, the importance of the accuracy of the shared information, and the human's preferences.

Finally, note the frequent occurrence of "human's attitudes" as an influencing factor in this model. If attempts to provide the human with adaptive assistance are to be successful, then preferences, biases, and quirks must be taken into consideration. It may be possible to design an aid which is very good at performing tasks and making decisions so as to optimize system performance, but the aid will be virtually useless if the human does not accept it. Failure to accept the aid could lead to a lack of cooperation and, if the human feels strongly enough, attempts to sabotage the computer's performance.

AN EXPERIMENTAL ENVIRONMENT

As noted in the Introduction, an experimental environment was developed as a tool for research into issues relevant to human-computer interaction. The primary goal in task development was to create conditions in which human and computer should interact in order to maximize system performance. Hence, it was necessary to develop a task in which the relative performance of human and computer could be expected to vary over time. In light of the relationships illustrated in the conceptual model, it appeared that the ability to manipulate resource requirements via changes in information availability and the nature and state of tasks would help in achieving this goal.

A secondary goal was to maintain a semblance of realism rather than create an "artificial" laboratory task. This was felt to be important because of the future possibility of investigating the effects of training and the nature of available information upon performance. Since training normally takes place within some meaningful context, it seems that research in the effects of training should also provide a context. However, in spite of this goal of realism, it is important to note that task characteristics were determined analytically from the issues which were to be investigated. Little attempt was made to provide a high-fidelity simulation of a real-world task.

Rationale and Overview

Target Recognition

The task environment consists of two tasks which must be performed concurrently. A visual target recognition task was chosen as one of the tasks in the scenario because of differences in the perceptual abilities of humans and computers. Humans readily impart meaning into what is seen, and are excellent at perceptual organization. Computers, on the other hand, have a great deal of difficulty analyzing scenes, but excel at figure rotation and template matching. Thus, humans should be better at identifying features in a meaningful scene, whereas computers should be better if the scene is a relatively homogeneous field of objects. The target recognition task is used to create conditions in which the human and computer should interact, by capitalizing upon these differences. The composition of the visual display changes over time, becoming more or less organizable.

When performing the target recognition task, subjects view a color graphic terrain display, which is illustrated in Figure 7. The terrain display depicts an intracoastal waterway with varying proportions of water. Water areas are colored blue. Also included in the terrain are green trees, tan ground, black buildings, white roads and parking lots, and cars and boats of assorted colors. To simulate flight over the terrain, the

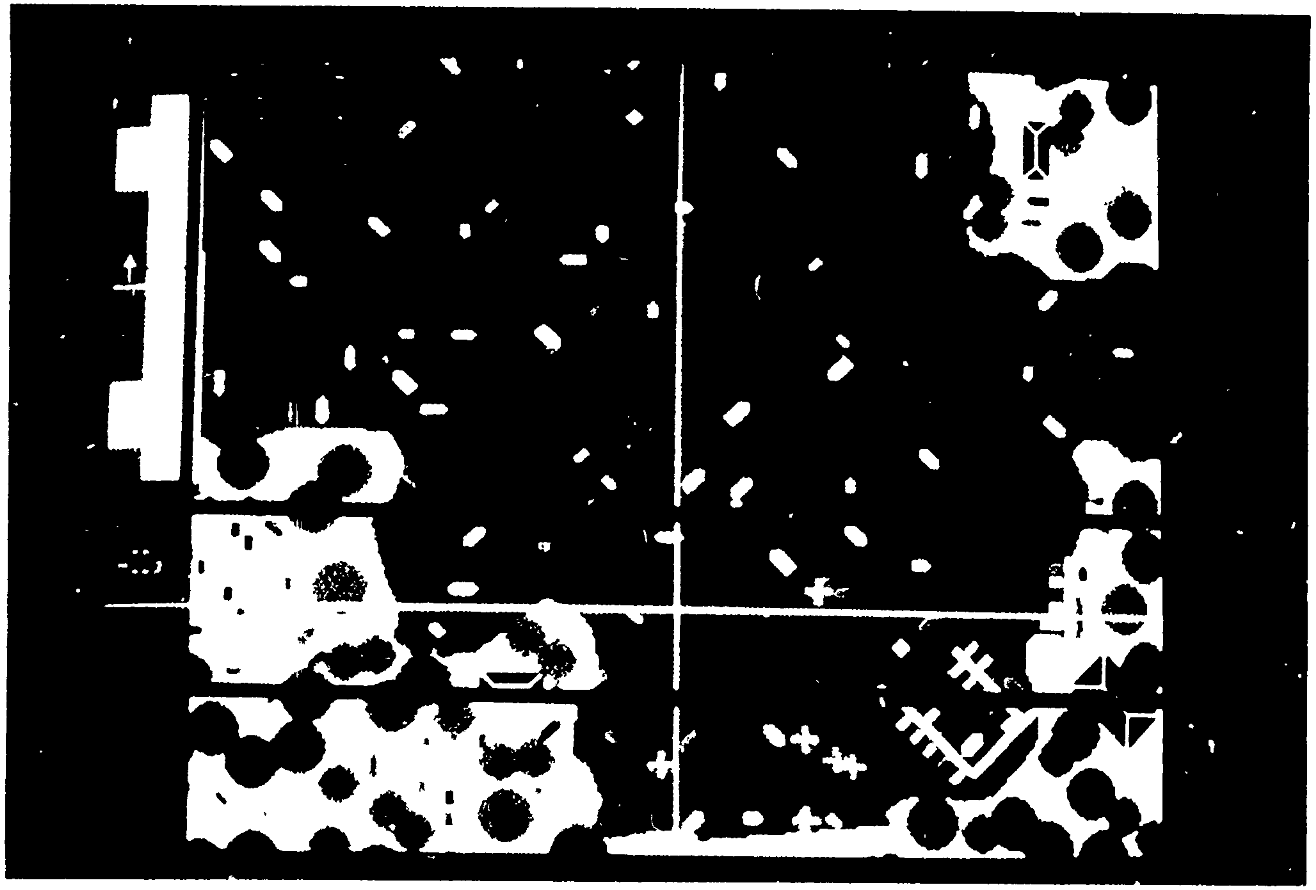

Figure 7. Task display.

display pans down the CRT. Subjects are given the goal of identifying or spotting boats of a certain type which are in use in the waterway.

Targets may be identified only when they are in the window defined by the heavy black horizontal lines. When the subject is identifying targets, identification is accomplished by using a mouse to position the cross-hair cursor on top of the target and then pressing a button on the mouse. When the button is pressed a "+" appears on the screen to acknowledge the action. Hits and false alarms are tallied in the upper left corner of the screen. (See Figure 7.)

It is also possible for the computer to perform the spotting task. If the human is in control of the allocation decision, the aid may be activated by positioning the cursor on top of the word "AID" (to the left of the terrain display in Figure 7), and pressing the button on the mouse. The cursor then disappears, and the aid identifies targets until the human resumes control by again pressing the button on the mouse.

The relative performance of human and computer may be expected to vary over time due to the changes in the amount of water in the display. In light of the human's perceptual abilities, this task should be easier for the human when the proportion of water in the window is low (such as when flying

over a narrow channel). This is because the human is able to organize the scene and automatically exclude a large portion (i.e., the land areas) from consideration.

The computer, on the other hand, is deficient in these organizational abilities, and scans the whole scene, identifying boats with a "template matching"* approach. As a result, the computer does not always differentiate land from water, and its false alarm rate increases with the proportion of land in the display. Thus, the human may be expected to excel when the proportion of water is low, and there is greater potential for the aid to excel when the proportion of water is high.

<u>Tracking</u>

The second task employed is a subcritical compensatory tracking task. The reasons for incorporating a second task into the scenario were as follows. First, since control of the target recognition task was to alternate between human and computer, it seemed desirable for the human to have something to do while the computer identified targets. Second, by requiring subjects to perform two tasks, the necessity for interaction with the computer can be assured. If target recognition were the only task required, it is feasible that subjects could maintain

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* The computer actually identifies objects on a probabilistic basis. See the discussion of task implementation for an explanation.

satisfactory performance over a wide range of conditions. However, it is highly unlikely that a human could perform both tasks satisfactorily under all conditions, particularly if tracking is made very difficult.

There were two reasons for choosing tracking as the second task. First, there is an extensive body of literature on tracking available to guide decisions as to appropriate task parameters, so less pilot testing is required. Second, the tracking task affords a fair amount of experimental flexibility. The difficulty of the tracking task can be changed over time (i.e., during a pass over the terrain display) or, more importantly, the tracking task can impose a relatively constant demand for resources. Hence, it is possible to observe the effects of changes in the difficulty of target recognition over time, while holding the difficulty of tracking constant. The nature of the tracking task thus allows considerable control over the degree to which the demands of the two experimental tasks compete for information processing resources (i.e., workload).

The display for the tracking task is shown in the upper left corner of Figure 7. The tracking display contains a green region flanked by yellow and red regions. The horizontal black line to the right of these regions moves up and down, and the arrow within the green region indicates the direction of the control input. The degree of instability of the controlled element is

determined by a difficulty parameter which is entered by the experimenter at the beginning of a run and remains constant throughout the run. The human's goal is to keep the black line within the green region by using bang-bang control via the space bar on the terminal keyboard. Should the moving pointer enter a red region, inputs from the mouse are disabled; hence, target identification is not possible unless the tracking task is also performed. When performing both tasks, the subject identifies targets with the right hand and tracks with the left.

With respect to the adaptive aiding concept, it is possible to specify qualitatively when the computer should be used in this environment. First, the aid should be used if its potential target identification performance exceeds that of the human. It is expected that this occurrence is most likely when tracking is non-trivial and the terrain is mostly water. Second, the aid should be used to look for boats if the human's tracking performance degrades to an unacceptable level. Excluding the case in which acceptable tracking is impossible due to the level of tracking difficulty, it is anticipated that this occurrence would also be related to the amount of water in the display.

Details of Task Implementation

A detailed discussion of task characteristics is provided here. It should be noted that many of these characteristics, such as difficulty parameters for the tracking task, panning

speed of the terrain display, etc., are not the result of software or hardware constraints. Many of the values were chosen somewhat arbitrarily, and can be varied as desired.

Target Recognition

Displays for both tasks are shown on an Envision 220 terminal, which has both a graphics memory plane and an alphanumeric screen which may overlay the graphics screen. Panning is made possible by zooming in and viewing approximately one eighth of the graphics plane at a time. At the beginning of an experimental run, the graphics screen is positioned over the lower left portion of the graphics plane. The screen pans up until the upper left portion of the graphics plane is visible, then shifts to the lower right portion of the plane and pans up until the upper right portion is visible. During transition from the upper left to lower right region, the viewing screen is darkened for 1-2 seconds. In this way, the entire graphics plane is viewed without overlap, in approximately 5-6 minutes.

Due to the sequence in which the graphics plane is viewed, the total terrain display consists of two long narrow portions which are drawn side-by-side on the graphics plane. Each portion is created by the experimenter using a graphics editor developed for the purpose, and is stored in a separate file. Four pictures may be created from one terrain file via programs which mirror and invert the contents of the file. Selection of terrain files

to be displayed on the right or left side of the graphics plane is made independently.

There are two types of object in terrain files. "Static" objects include buoys, coastline, and all objects on land and in marinas. The locations of these objects are specified during creation of the terrain file, and do not change. Boats in the waterway are "dynamic", in that their locations are determined randomly by the computer during the experimental session. When creating the terrain file, the experimenter specifies the area in which boats should be placed and the number of boats the area should contain. Because the locations of targets can be changed after each pass over the graphics plane, it is possible to have multiple passes over the terrain during an experimental session. This eliminates the need to redraw the terrain display after each pass, which requires approximately 5 minutes.

Terrain composition. The picture in each terrain file may be viewed as consisting of horizontal segments the size of the spotting window shown in Figure 7. In the files created thus far, the proportion of water in each segment takes one of six values: 1.0, 0.8, 0.7, 0.4, 0.3, or 0.2. For practical purposes, segments may be viewed as predominantly land or predominantly water. Terrain segments are grouped so that there are two large areas which are mostly water, and three areas which are predominantly land.

Figure 8 shows a simple block pattern for the coastline which was used in the creation of one of the terrain files. (As may be seen in Figure 7, coastlines appear much more irregular than this pattern suggests.) Terrain segments are indicated by dashed lines. Targets in areas outside the heavy double lines (i.e., the extreme top and bottom of the figure) may not be identified by the subject because those areas never enter the spotting window, although they do appear on the display.

Recall that this terrain is viewed from bottom to top. As the graphics screen passes over the terrain, terrain segments traverse the spotting window in approximately 20 seconds. If control of the target recognition task is transferred from one partner to the other when the composition of the terrain changes from predominantly land to predominantly water or vice versa, there are three to four opportunities for human and computer to interact. These opportunites occur at roughly 1-minute intervals.

<u>Object density and aid performance</u>. As mentioned earlier, the number of objects in the display is established by the experimenter during the creation of the terrain file. It is important to control the number of objects in the display because the computer aid identifies objects as targets on a probabilistic basis. Thus, the quality of the aid's performance depends to a great extent upon the number of objects present.

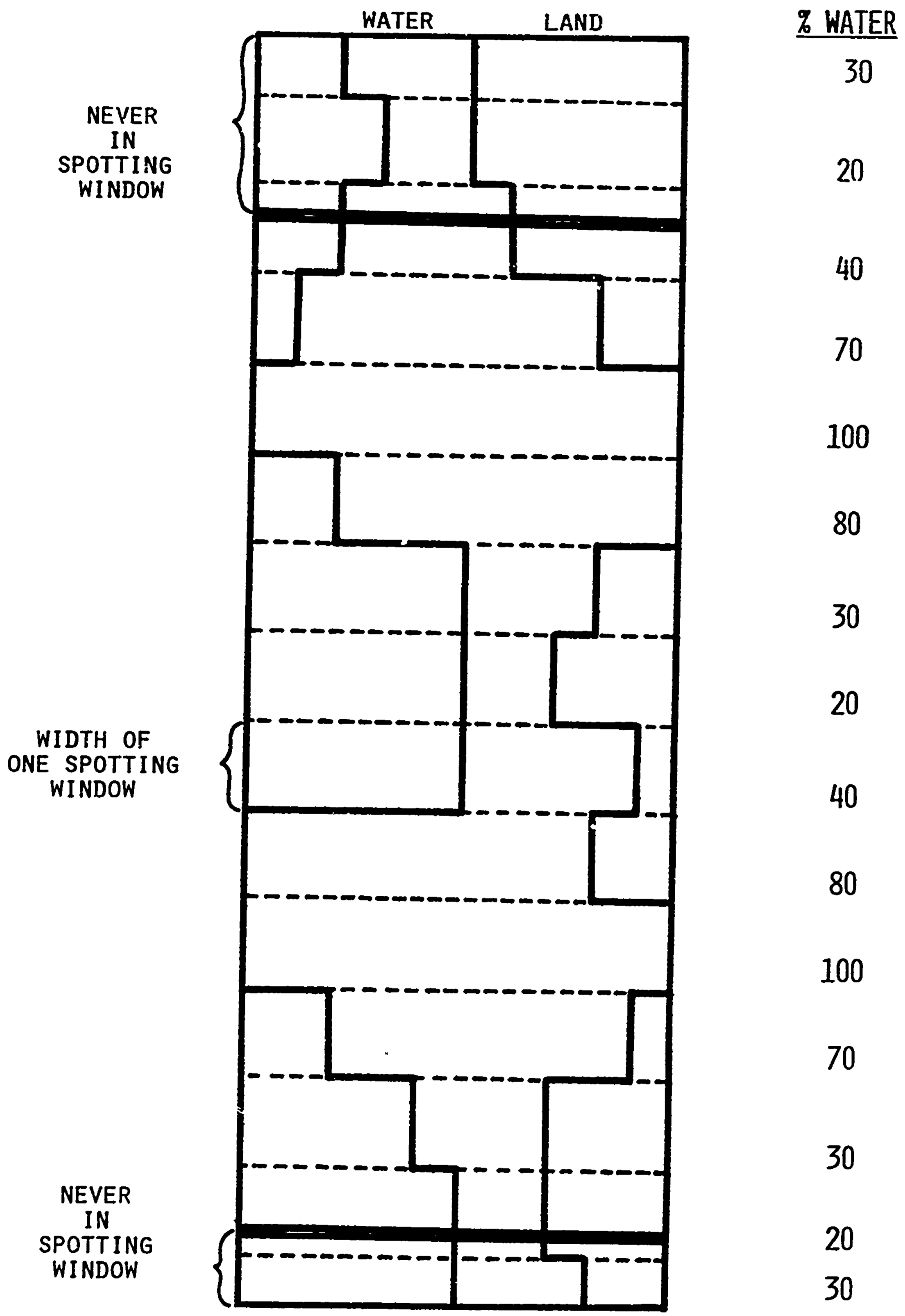

Figure 8. Sample coastline pattern.

Large objects such as trees and houses are never identified as targets by the computer, so the density of these objects is not important. There are three classes of objects which affect the computer's performance. Type A boats are the target boats. Looking at Figure 7, the large boats which are pointed at one end are type A boats. Type B boats are sometimes confused with type A boats by the computer, and are large boats pointed at both ends. (See Figure 7.) Type C objects are rarely identified as targets by the computer, and include small boats, buoys, and cars.

The density of objects in each of these categories is as follows. In a terrain segment which is 100% water, there are 10 type A boats, 10 type B boats, and 10 type C objects (i.e., small boats and buoys). A segment which was 100% land (which never occurs) would contain five type A boats, five type B boats, and 50 type C objects (i.e., small boats and cars). The number of objects in a terrain segment is related to the proportion of water in that segment. For example, a terrain segment which was 50% water would contain five type C objects in the water and 25 type C objects on land.

When the computer is in control of the spotting task, the probability that an object will be identified as a target depends upon the type of object and whether it is on land or water. These probabilities are shown in Table 2. Given these probabilities and the density of various objects on land and

water, it is possible to predict the computer's spotting performance with respect to each type of terrain. This is shown in Table 3.

Tracking

The display for the tracking task is drawn on the alphanumeric screen of the Envision, and overlays the graphics screen. By using separate screens for displaying the two tasks, it is possible for the tracking display to remain stationary as the terrain display moves. The graphic appearance of the tracking task is made possible by redefining the lower-case character set of the Envision.

The dynamic behavior of the tracking task is represented in Equations 1 and 2.

$$z((n+1)T) = r + c(z(nT)), \quad T = 1/6 \text{ sec.} \tag{1}$$

$$c = 1 + d/40 \tag{2}$$

The tracking task is a modification of the tracking task developed by Jex, McDonnell, and Phatak (1966). Direction of movement of the controlled element is governed by the parameter "r", which toggles between $\pm$ maximum input. The value of the difficulty parameter, "d", is supplied by the experimenter at the beginning of an experimental run, and may have a value from 1 to 10.

Table 2

Probability that Aid will Identify

Object as Target

Type of Object	Location: Water	Location: Land
A	.95	.50
B	.05	.05
C	.01	.01

Table 3

Performance of Aid over Different Terrain Types

% Water	Targets Present	Hits	False Alarms	Net Score (Hits-False Alarms)
100	10	9.5	0.6	8.9
80	8	7.6	1.13	6.47
70	7	6.65	1.39	5.25
40	4	3.8	2.19	1.61
30	3	2.85	2.45	0.39
20	2	1.9	2.72	-0.82

PILOT RESEARCH

Considering the characteristics of the experimental environment, the following effects of task parameters upon performance may be anticipated. First, performance on the tracking task and/or the target recognition task should degrade as tracking difficulty is increased. Second, performance on the target recognition task and/or the tracking task should be worse when the terrain in the spotting window is predominantly water rather than land. With respect to the adaptive aiding concept, the computer should identify targets when the human's target recognition performance degrades, <u>or</u> when the human's tracking performance degrades. A pilot study was conducted to evaluate the accuracy of some of these ideas by assessing the effects of task parameters on subjects' performance. Since one of the purposes of this experiment was to identify conditions in which the need for computer assistance would be likely, no aid was available to subjects.

Two subjects served in three sessions each. The first session served as training and consisted of one 5-minute run at each of four levels of tracking difficulty (i.e., "d" was equal to 1, 3, 5, or 7). In the second and third sessions, the easiest tracking condition (d = 1) was excluded and only three levels of tracking difficulty were used. Thus, there were two independent variables in the pilot study: tracking difficulty and terrain

composition. Dependent measures included rms tracking error, spotting accuracy (i.e., percent identified) and spotting latency (i.e., average time to identify a target once it entered the spotting window).

Results

The results of this study are presented graphically in Figures 9-11. Time is represented on the abscissa of each graph, as the values shown represent the sequence of terrain types encountered by subjects over the course of a run. One interval on the abscissa corresponds to approximately 20 seconds of real time. To facilitate interpretation of these figures, terrain is also grouped via the horizontal lines as either predominantly land or predominantly water. The break or dashed line in the middle of each graph reflects missing data. Due to hardware constraints, targets in these areas are not accessible to subjects, and there is a 1-2 second interval of "dead time" in the middle of each run.

Figure 9 depicts rms tracking error for three levels of tracking difficulty, averaged across both subjects. Two characteristics of Figure 9 are noteworthy. First, rms tracking error increased with increases in the difficulty parameter of the tracking task. Second, rms tracking error increased with the amount of water in the display. This effect seems to have been stronger when tracking was relatively easy, but is noticeable at each of the levels of tracking difficulty employed in this study.

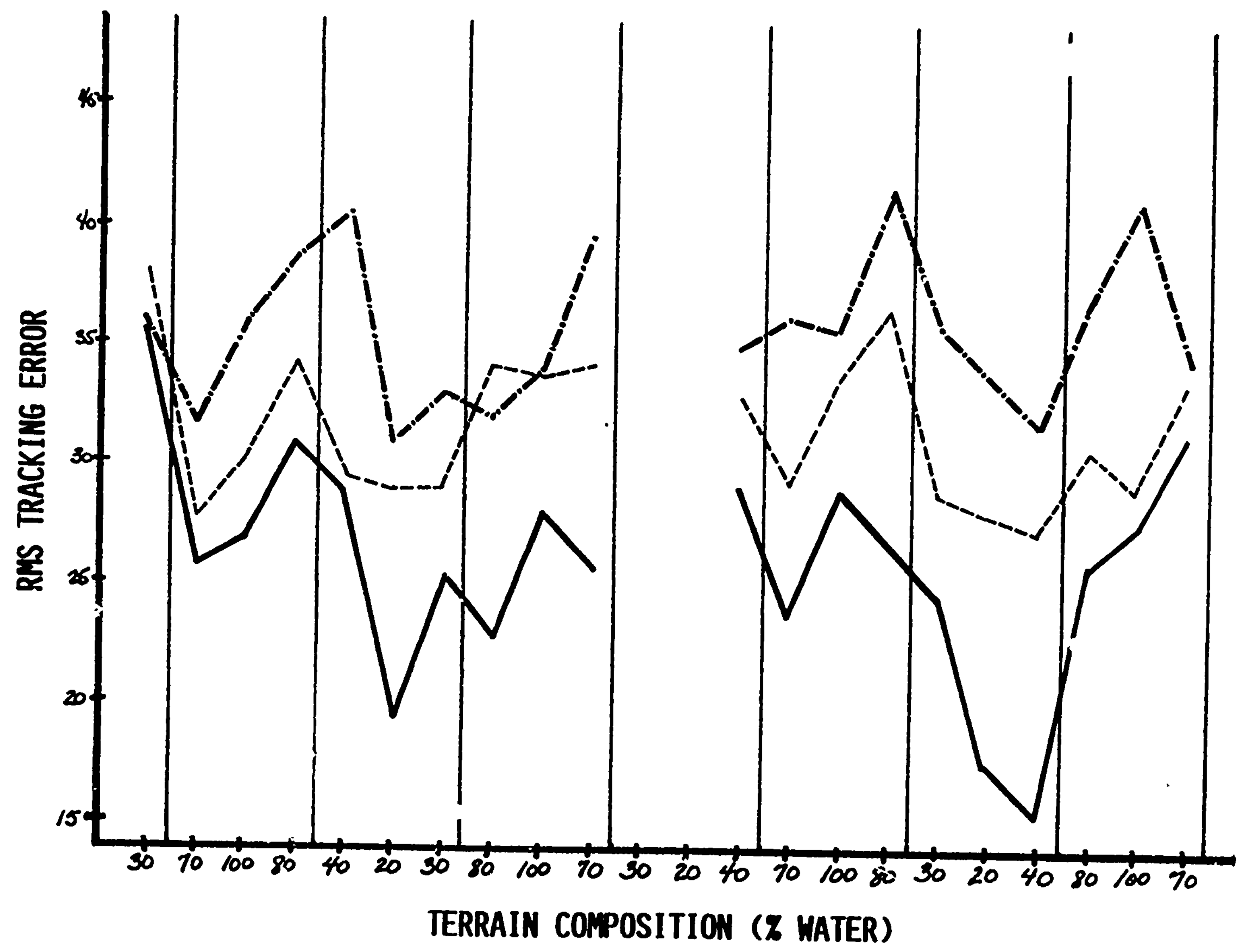

Figure 9. RMS tracking error.

From Figures 10 and 11, it may be ascertained that performance on the target identification task was also affected by changes in the terrain composition. Increases in the proportion of water in the display were accompanied by decreases in spotting accuracy (although small) and increases in spotting latency. Unlike rms tracking error, there was no noticeable effect of tracking difficulty manipulations upon target identification; as a result, the plots in Figures 10 and 11 represent performance averaged across three levels of tracking difficulty.

If the three dependent measures are compared to each other, some clear relationships emerge. First, there is an obvious negative relationship between spotting accuracy and spotting latency. Product-moment correlations at different levels of tracking difficulty ranged from -.61 to -.70. Of course, these results were obtained with only two subjects, so generalizations should be made with caution; however, if further experiments continue to reveal this relationship, this may have implications for online adaptation.

Although spotting accuracy is the stated performance criterion, its utility as an online measure is limited due to two factors. First, observed decrements in spotting accuracy were quite small, usually no more than 2-3 missed targets. Second, it seems desirable to be able to offer assistance <u>before</u> a target is

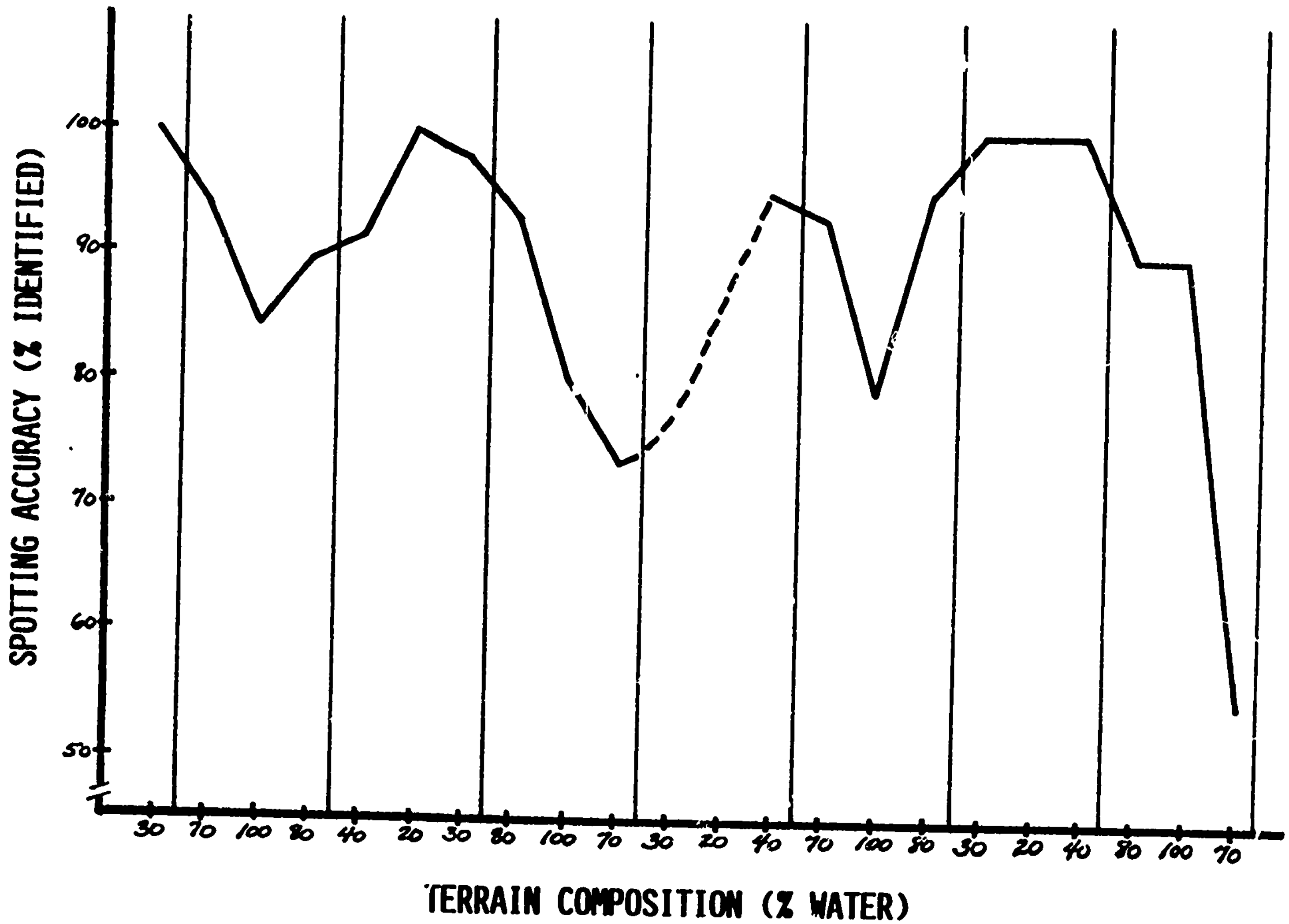

Figure 10. Spotting accuracy.

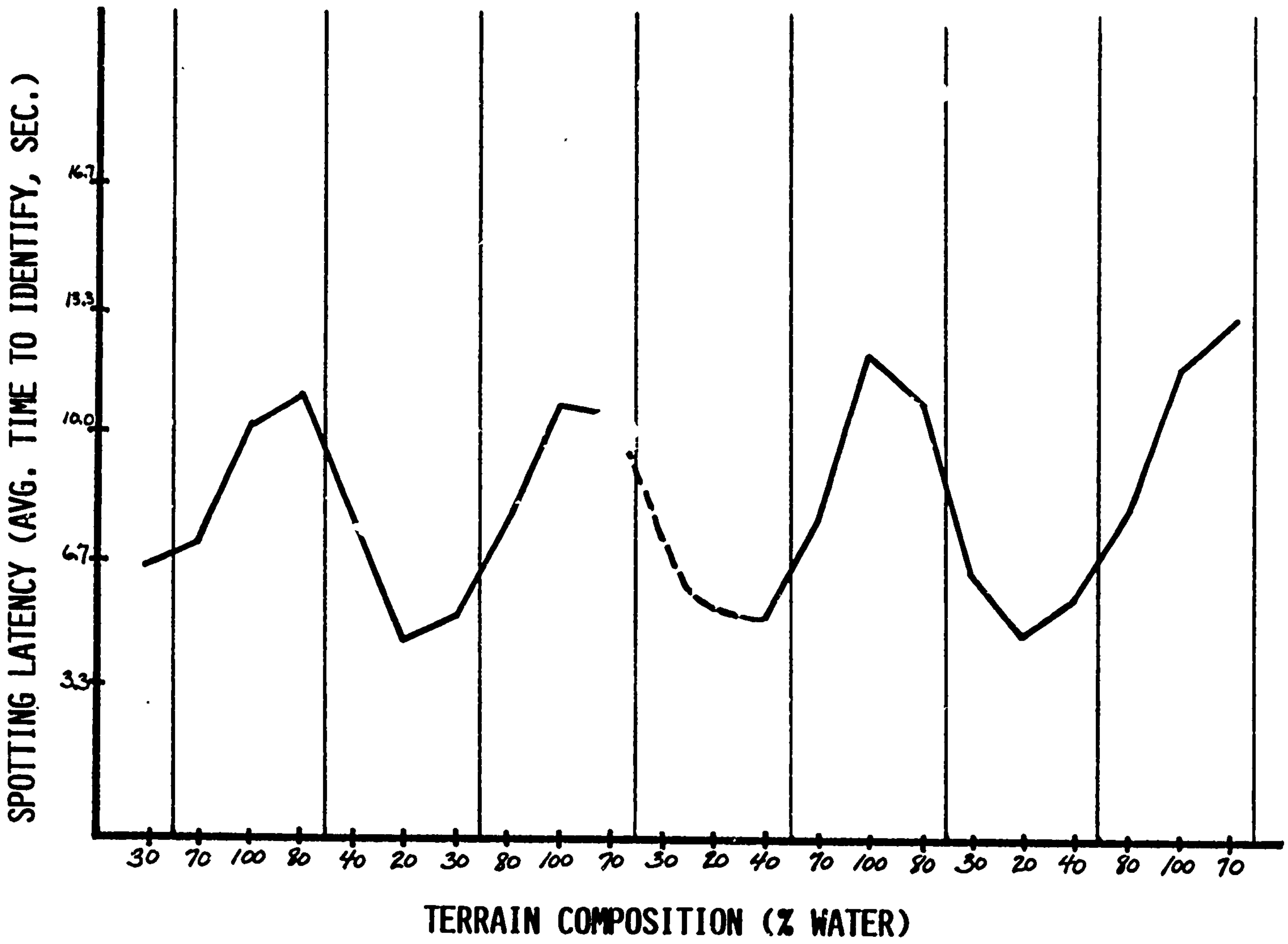

Figure 11. Spotting latency.

missed, rather than stepping in too late to do any good. Spotting latency is easily assessed online; if the relationship of latency to accuracy proves to be sufficiently strong, the latency measure may be useful as a basis for online computer adaptation.

It may also be noted that rms tracking error is related to both spotting accuracy and spotting latency. Since it is an easily calculated, continuous measure, rms tracking error may also be useful as a basis for decision making. However, the results from this pilot study indicate that rms tracking error may not be as useful for this purpose as spotting latency, because its response to task changes considerably lags the response of spotting latency to these changes. (A comparison of Figures 9 and 11 reveals a difference of almost 20 seconds in the most difficult tracking condition.)

Summary

The primary reason for conducting this pilot study was to examine the effects of task parameters upon performance of the tracking and target recognition tasks. Prior to conducting this research, it was anticipated that performance of both the tracking task and target recognition task would reflect manipulations of the difficulty of either task. The results of this experiment were not totally consistent with these expectations.

Tracking performance was found to degrade with increases in tracking difficulty and with increases in the difficulty of the target recognition task. Target identification performance, on the other hand, was affected only by changes in the proportion of water in the terrain display, and was relatively insensitive to changes in the difficulty of the tracking task. Although the effects of task parameters upon performance were not entirely predicted, the effects observed indicate that the creation of the desired experimental conditions is possible within the task environment. Additionally, the possibility of making task allocation decisions online based upon dependent measures such as spotting latency appears promising.

SUMMARY AND CONCLUSIONS

In the Introduction, shortcomings to the traditional approach to computer aiding were pointed out, and the potential value of the concept of adaptive aiding was emphasized. It was also noted that a number of issues, which are outlined in the first-year report, must be investigated before the concept may be implemented. The purpose of this year's effort was to begin investigation of these issues.

There were three major accomplishments this year. First, relationships between variables believed to have potential effects upon the manner in which adaptive aiding should be implemented were summarized in a conceptual model of human-computer interaction. Second, an experimental environment

was developed so that relationships expressed in the conceptual model may be investigated. Third, a pilot study investigating the effects of task characteristics upon performance was performed.

In light of the results of the pilot study, it appears that the objective of creating conditions in which human and computer should interact is achievable. By manipulation of task parameters, it is possible to cause differences in performance that are somewhat predictable. It is not yet possible to make adaptive allocation decisions online, but the realization of this capability seems feasible.

There are five components in the conceptual model which may be manipulated to affect performance. These are 1) nature and state of tasks, 2) nature of human-computer communication, 3) human factors of displays and controls, 4) displays and other information sources, and 5) prior training and experience. Focus thus far has been on manipulation of task characteristics (i.e., the first component listed). If a full evaluation of the relationships expressed in the model is desired, it will be necessary to manipulate the other components as well.

Although nature of human-computer communication has not yet been varied, it is possible to imagine several of ways in which this may be accomplished. For example, the human could be

required to enter a number of keystrokes on the terminal keyboard instead of pressing a single button on the mouse. Similarly, manipulation of the human factors of displays and controls could be achieved fairly easily by altering, for example, S-R compatibility.

In contrast, investigation of the effects of training or information availability does not seem very promising in this environment. This is because task performance is possible without a great deal of information or training. Some information is required to understand how the computer performs the target recognition task, but it is not clear that such information would (or could) alter performance very much. In general, the task environment does not seem "rich" enough to allow investigation of these effects, and elaboration will be required.

It is anticipated that the focus in future work will be upon relationships between training, information available, and nature of human-computer communication. More specifically, the tradeoffs between explicit and implicit communication will be of interest. It is necessary to consider training and information sources in conjunction with this issue, because it is reasonable to expect that knowledge requirements are different for these two forms of communication. For example, a greater understanding of the functioning of the computer aid may be required in order for

implicit communication to be effective. One type of message which may necessarily be communicated implicitly is that the aid's performance has degraded. Investigation of knowledge and information required to detect a degradation of the aid's performance will be particularly important.

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